AN INVESTIGATION INTO THE EFFECTIVENESS OF VIRTUAL REALITY-BASED LEARNING

Elinda Ai Lim Lee
BA (Hons) (USM); MBA (Information Systems) (USQ)

This thesis is presented for the degree of Doctor of Philosophy of Murdoch University
2011

DECLARATION

I declare that this thesis is my own account of my research and contains as its main content work which has not previously been submitted for a degree at any tertiary education institution.

____

Elinda Ai Lim Lee

To my husband Boon Leng and sons Timothy and Aaron for their continuing love and support

ABSTRACT

This study focused on the effectiveness of using desktop virtual reality (VR) for learning. It addressed the question: Does, and how does, desktop VR influence the cognitive and affective learning outcomes? Cognitive outcome was measured through academic performance whereas affective learning outcomes were measured through perceived learning effectiveness and satisfaction.

The main aims of this study were thus two-fold. First, it investigated ‘‘Does desktop VR influence the learning outcomes?’’ by comparing a desktop VR-based learning environment and a conventional classroom learning practice, and it further conducted the aptitude-by-treatment interaction research to determine if individual differences interact with different learning environments. Two learners’ aptitudes were studied: spatial ability and learning style. In addition, individual differences were further analyzed for the VR-based learning environment because their influence in desktop VR-based learning has been rarely studied. An evaluation that employed a quasi-experimental design was conducted to investigate the learning effectiveness of desktop VR-based learning, and to investigate the effect of learners’ aptitudes on learning. A total of 370 students, aged between 15 to 17 years old from four randomly selected co-education Malaysian secondary schools participated in this study. The findings of this study have supported the general hypothesis that the VR-based learning environment positively affects the cognitive and affective domains of learners. This study has provided empirical evidence on the merit of using desktop VR for learning. Furthermore, it was found that desktop VR could accommodate learners’ individual differences in terms of learning styles.

Next, the research focused on the development of a theoretical model of determinants for effective desktop VR-based learning to understand how a desktop VR system is capable of enhancing and improving the quality of student learning, and the types of students that would benefit from this technology. Various relevant constructs and measurement factors were identified to examine how desktop VR enhances the learning outcomes and the hypothesized model was analyzed using structural equation modeling (SEM). By tradition, the practice of applying correlation analysis to data and hypotheses does not reflect the causal relationships between constructs, but SEM produces a highly viable alternative in determining the causal relationships among constructs. This type of analysis is lacking in desktop VR-based learning.

In the hypothesized model of this study, VR features indirectly influenced the learning outcomes through the mediation of usability (interaction experience) and learning experience. Learning experience which was individually measured by the psychological factors—that is, presence, motivation, cognitive benefits, control and active learning, and reflective thinking—took central stage in affecting the learning outcomes. The moderating effects of student characteristics such as spatial ability and learning style were also examined. Moreover, latent mean difference testing in SEM was conducted to determine the influence of student characteristics on the perception of VR features in the desktop VR-based learning environment. The findings have supported the indirect effect of VR features on the learning outcomes, which was mediated by the usability and learning experience. The results show instructional designers and VR developers how to improve the learning effectiveness and further strengthens their desktop VR-based learning implementation. Furthermore, academia can use the findings of this study as a basis to initiate other related studies in the desktop VR-based learning area.

ACKNOWLEDGEMENTS

I would like to start by greatly thanking God for giving me the wisdom and strength to complete this thesis. Next, I would like to express my greatest gratitude to my supervisors, Associate Professor Dr. Kevin Wong and Associate Professor Dr. Lance Fung, for their dedication and commitment in supervising this research project. Their expertise, encouragement, guidance and understanding have made a huge difference to the progress of this thesis. I value their mentorship, boundless support, expert direction and the friendship that we built through the years.

My enormous thanks go to the Malaysian Ministry of Higher Education and MARA University of Technology for giving me an opportunity to pursue my dream. Special thanks to Professor Ir Dr. Sahol Hamid Abu Bakar, Professor Dr. Ibrahim Abu Shah, Professor Dr. Zainal Abu Bakar and Professor Dr. Jamil Hamali from MARA University of Technology for their support and encouragement. My deepest appreciation also goes to Tactus Technologies, New York for granting me a license to use the V-Frog^{TM} software for this research. This thesis would not be possible without the staff, teachers and students who participated in this study. Their interest in my project, helpfulness and support are very much appreciated.

My sincere appreciation is extended to Dr. Tanya McGill from the School of Information Technology, Murdoch University and Dr. Andrew McConney from the School of Education, Murdoch University for sharing their expertise and knowledge.

Most of all, I wish to thank my parents, parents-in-laws, the rest of my family, friends and colleagues for their prayers, inspiration and support.

TABLE OF CONTENTS

CHAPTER 4 METHODOLOGY

CHAPTER 7 DISCUSSION

LIST OF FIGURES

LIST OF TABLES

LIST OF DEFINITIONS

To ensure that the terminology used in this thesis is clear, this section includes the definition of the key terms used throughout the thesis.

An accommodator learner: A learner who fulfills Kolb's definition of accommodator, a diverger learner with stronger Kolb's characteristics of concrete experience than reflective observation, and a converger learner with stronger Kolb's characteristics of active experimentation than abstract conceptualization.

An assimilator learner: A learner who fulfills Kolb's definition of assimilator, a diverger learner with stronger Kolb's characteristics of reflective observation than concrete experience, and a converger learner with stronger Kolb's characteristics of abstract conceptualization than active experimentation.

A high spatial ability learner: A learner who scores above the median in the spatial ability test.

A low spatial ability learner: A learner who scores below the median in the spatial ability test.

Cognitive benefits: It refers to better memorization, understanding, application and overall view of the lesson learned.

Construct: See *latent variable*.

Control and active learning: It refers to learner control and active participation while interacting with the virtual reality system. Learners can make their own decision on their learning pace, sequencing, content of instruction, and amount of practice in a learning environment (Kinzie, Sullivan, & Berdel, 1988; Milheim & Martin, 1991).

Conventional classroom learning method: A learning environment with PowerPoint slides based on the lecture method. Information and knowledge were transmitted by teachers to students.

Desktop VR: An interactive three-dimensional computer generated image that can be manipulated. It is implemented on a conventional personal computer without introducing any additional peripheral (Chen, Toh, & Wan, 2004, Neale & Nichols, 2001; Strangman & Hall 2003; Inoue 2007), and is also referred to as a non-immersive VR (Aoki, Oman, Buckland, & Natapoff, 2008; Ausburn & Ausburn, 2004; Chen et al., 2004; Inoue, 2007; Youngblut, 1998).

Desktop VR-based learning environment: A self-directed learning environment with desktop virtual reality.

Immediacy of control: The ability to change the view position or direction, giving the impression of smooth movement through the environment, and the ability to pick up, examine and manipulate objects within the virtual environment (Dalgarno, Hedberg, & Harper, 2002).

Indicator: Observed value used as measure of a latent variable. It is also known as observed or measured or manifest variable (Hair, Black, Babin, Anderson, & Tatham, 2006).

Latent variable: Operationalization of a construct in structural equation modeling. It is also known as a construct, which cannot be measured directly but can be represented or measured by one or more indicators (Hair, et al., 2006).

Learning experience: A psychological state or subjective phenomenon that resulted from the learner's observation and interaction with objects, entities and/or events in the VR-based learning environment (Schuemie, Van Der Straaten, Krijin, & Van Der Mast, 2001).

Learning outcomes: The learning effectiveness of the virtual reality-based learning environment which is measured by performance achievement, perceived learning effectiveness and satisfaction.

Learning style: One's preferred method of perceiving and processing information (Kolb, 1984).

Measured variable: See *indicator*.

Measurement model: A SEM model that specifies the relationships between the observed variables and each latent variable (Byrne 2001; Hair et al., 2006).

Motivation: It refers to the magnitude and direction of behavior. It is the choices people make as to what experiences or goals they will approach or avoid, and the degree of effort they will exert in that respect (Keller, 1983, p. 389).

Non-VR mode: A conventional learning mode that relies on the lecture method. PowerPoint slides were used to deliver the lecture.

Observed variable: See *indicator*.

Perceived ease of use: It is the degree to which a person believes that using a particular system would be free of effort (Davis, 1989).

Perceived learning effectiveness: It is the user's perception of the learning quality in the VR-based learning environment.

Perceived usefulness: It is defined as the extent to which individuals believe a system will help them perform (Davis, 1989).

Performance achievement: The academic achievement of a learner after interacting with the VR system, which is measured by the posttest scores.

Reflective thinking: It is defined as active, persistent, and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it and the conclusion to which it tends (Dewey, 1933, p. 9).

Representational fidelity: The scene realism provided by the rendered 3-D images, and the scene realism provided by temporal changes to these images (Dalgarno, et al., 2002).

Presence: The user's subjective psychological response to a system. It is a human reaction to a given level of immersion (Slater, 2003).

Satisfaction: The affective attitude or response of a user towards the VR-based learning environment.

Spatial ability: It refers to a group of cognitive functions and aptitudes that is crucial in solving problems that involve manipulating and processing visuo-spatial information (Bodner & Guay, 1997; Hannafin, Truxaw, Vermillion, & Liu, 2008; Lajoie, 2008; Rafi, Anuar, Samad, Hayati, & Mahadzir, 2005), because it is the mental process used to perceive, store, recall, create, edit and communicate a spatial image (Linn & Petersen, 1985).

Structural equation modeling (SEM): A multivariate data analysis technique used to estimate a series of interrelated dependence relationships simultaneously.

Structural model: A model that defines the interrelationship among the latent variables in SEM (Byrne 2001, Hair et al., 2006).

Usability: The quality and accessibility of the virtual reality software used in this study which is measured by perceived usefulness and perceived ease of use.

Virtual reality (VR): A 3-D synthetic environment that allows users to interact intuitively in real time with the virtual world and provides a feeling of immersion to the users (Allen et al., 2002; Auld, 1995: Ausburn & Ausburn, 2004; Ausburn & Ausburn, 2008; Ausburn, Martens, Washington, Steele, & Washburn, 2009; Beier, 2004; Burdea & Coiffet, 2003; Inoue, 2007; Pan, Cheok, Yang, Zhu, & Shi, 2006; Roussou, 2004; Strangman & Hall, 2003). It refers to both non-immersive and immersive VR (Ausburn & Ausburn, 2004: Beier, 2004; Inoue, 2007; Strangman & Hall, 2003).

VR affordances: The qualities of the VR learning environment which include scene realism and immediacy of control that allow an individual to perform an action in the learning environment.

VR features: The attributes of the desktop virtual reality.

VR mode: A learning mode that employs the desktop VR-based learning environment. The virtual reality software, V-Frog™ is used for learning.

LIST OF ABBREVIATIONS

AC	:	Abstract conceptualization
AE	:	Active experimentation
AGFI	:	Adjusted goodness-of-fit index
AMOS	:	Analysis of Moment Structures
ANCOVA	:	Analysis of covariance
ANOVA	:	Analysis of variance
ATI	:	Aptitude-by-treatment Interaction
CAL	:	Computer-assisted learning
CAVE	:	Cave Automatic Virtual Environment
CE	:	Concrete experience
CFI	:	Comparative fit index
CSCLIP	:	Computer-supported collaborative learning requiring immersive presence
C-Vision	:	Collaborative Virtual Interactive Simulations
EVL	:	Electronic Visualization Laboratory
GFI	:	Goodness-of-fit index
HMDs	:	Head-mounted devices
IMI	:	Intrinsic Motivation Inventory
KLSI	:	Kolb Learning Style Inventory
KMO	:	Kaiser-Meyer-Olkin
M	:	Mean
MARVEL	:	Virtual Laboratory in Mechatronics
NICE	:	Narrative-based, Immersive, Constructionist/Collaborative Environments

PIP	:	Personal Interaction Panel
P_U	:	Upper Group
P_L	:	Lower Group
RMSEA	:	Root mean square error of approximation
R^2	:	Squared multiple correlations
RO	:	Reflective observation
SD	:	Standard deviation
SEM	:	Structural Equation Modeling
SPSS	:	Statistical Package for Social Sciences
TAM	:	Technology acceptance model
TLI	:	Tucker Lewis Index
TRA	:	Theory of Reasoned Action
VR	:	Virtual reality
VRML	:	Virtual Reality Modeling Language
VRPS	:	Virtual Reality Physics Simulation
X3D	:	eXtensible 3D Graphics
2-D	:	Two-dimensional
3-D	:	Three-dimensional

LIST OF PUBLICATIONS AND CONTRIBUTIONS OF THE THESIS

Journal Paper

J1. Lee, E. A.-L., Wong, K. W. (2008). A Review of Using Virtual Reality for Learning, *Transactions on Edutainment I*, LNCS 5080, 231-241.

J2. Lee, E. A.-L., Wong, K. W., & Fung, C. C. (2010). How Does Desktop Virtual Reality Enhance Learning Outcomes? A Structural Equation Modeling Approach, *Computers and Education*, *55*(4), 1424 – 1442

J3. Lee, E. A.-L., Wong, K. W., & Fung, C. C. (2010). Learning with Virtual Reality: Its Effects on Students with Different Learning Styles. *Transactions of Edutainment IV*, LNCS 6250, 79 – 90.

J4. Lee, E. A.-L., Wong, K. W., & Fung, C. C. (2010). Learning with Non-immersive Virtual Reality: The Role of Learners' Spatial Ability, Paper submitted to *Virtual Reality* (Under review).

Conference Paper

C1. Lee, E. A.-L., Wong, K. W., & Fung, C. C. (2008). Virtual Reality: An Emerging Technology for Learning. *Proceedings of the Ninth Postgraduate Electrical Engineering & Computing Symposium*, Perth, Australia.

C2. Lee, E. A.-L., Wong, K. W., & Fung, C. C. (2009). Educational Values of Virtual Reality: The Case of Spatial Ability. In C. Ardil (Ed.) *Proceedings of the World Academy of Science, Engineering and Technology*, Paris, France.

C3. Lee, E. A.-L., Wong, K. W., & Fung, C. C. (2009). Learning Effectiveness in a Desktop Virtual Reality-Based Learning Environment. In S. C. Kong, H. Ogata, H. C. Arnseth, C. K. K. Chan, T. Hiroshima, F. Klett, J. H. M. Lee, C. C. Liu, C. K. Looi, M. Milrad, A. Mitrovic, K. Nakabayashi, S. L. Wong & S. J. H. Yang (Eds.), *Proceedings of the17th International Conference on Computers in Education [CDROM]*. Hong Kong: Asia-Pacific Society for Computers in Education.

C4. Lee, E. A.-L., Wong, K. W., & Fung, C. C. (2009). Virtual Reality and Performance: An Approach in the Light of Spatial Ability. *Proceedings of the Tenth Postgraduate Electrical Engineering & Computing Symposium*, Perth, Australia.

Summary of the Contributions of the Thesis

Chapter	Contributions	Paper No.
Chapter 1—Introduction Chapter 2—Literature Review	Literature survey on previous work to apply virtual reality (VR) technologies for learning. Literature search on frameworks that could guide desktop VR-based learning development efforts. The technical capability of VR to support constructivist learning principles was presented.	J1, C1
Chapter 2—Literature Review Chapter 3—Research Framework & Hypotheses Development	The articulation of the impact of virtual reality in helping learners with different spatial abilities to create internal representations of complex three-dimensional structures, such competence being of paramount importance in the field of science and mathematics. The proposal of aptitude-by-treatment interaction research to study the effect of individual differences on different instructional treatments.	C2
Chapter 5—Results : Learning Effectiveness of a Desktop VR-based Learning Environment and ATI Research Chapter 7—Discussion Chapter 8—Conclusions	The findings of this study contribute to our understanding of the learning outcomes of a desktop VR-based learning environment and provide empirical evidence of the merit of desktop VR-based learning to educators. The learning effectiveness in desktop VR-based learning could be justified and thus used to encourage the application of VR in educational settings to improve students' performance. Furthermore, to provide the students a positive, fun and valuable learning experience.	C3
	The findings enlighten educators on the influence of a desktop VR-based learning environment on learners with different spatial abilities.	C4
	This study also investigated the effects of VR on learners with different learning styles. The findings imply that VR provides equivalent cognitive and affective benefits to learners with different learning styles, and it could accommodate individual differences with regards to students' learning styles.	J3

Chapter	Contributions	Paper No.
	Aptitude-by-treatment interaction (ATI) research was conducted to investigate the interaction effect between the learning modes (VR and Non-VR mode) and the learners' spatial abilities, with regard to students' performance achievement. The finding is in agreement with the ability-as-compensator hypothesis where the VR mode benefits more to the low spatial ability learners.	J4
Chapter 2—Literature Review Chapter 3—Research Framework & Hypotheses Development Chapter 4—Methodology Chapter 6—Results : 'How Does Desktop VR Enhance Learning Outcomes?' Chapter 7—Discussion Chapter 8—Conclusions	A broad framework that identifies the theoretical constructs and their relationships in a desktop VR-based learning environment has been developed and the fit of the theoretical model has been systematically and empirically tested with structural equation modeling. The results supported the indirect effect of VR features on the learning outcomes, which was mediated by the interaction experience (i.e. usability) and the psychological factors of learning experience (i.e. presence, motivation, cognitive benefits, control and active learning, and reflective thinking). An initial theoretical model of the determinants of learning effectiveness in a desktop VR-based learning environment is contributed. This study makes a significant contribution by bringing us one step closer to understand the potential of desktop VR technology to support and enhance learning. The findings not only enlighten us about what has occurred but also how the learning has occurred in a desktop VR-based learning environment.	J2